The effect of elevated temperatures on Sidman avoidance*

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Sidman avoidance performance persists during heat exposure. Disruption of avoidance performance coincided with disruption of the thermoregulatory capacity of the organism. The results suggest that avoidance performance not only regulates shocks received but also contributes to the regulation of body temperature.

Performance maintained by food, water, or brain-stimulation reinforcement will be disrupted upon exposure to elevated ambient temperatures (e.g., Barofsky, Robinson, & Hurwitz, 1970; Briese, 1965). In contrast, rats trained on a discriminated avoidance schedule and acutely exposed to the heat show no decrement in performance (Barofsky & Hurwitz, 1968). The disruption in appetitively reinforced performance coincides with the elicitation of an alternative set of behaviors (e.g., saliva spreading) which contribute to the regulation of body temperature (Barofsky, 1969; Hainsworth, 1967). Parsimony dictates that a similar explanation would account for avoidance performance in the heat; namely, that the persistence of avoidance performance in the heat contributes to the regulation of body temperature. The purpose of the present experiment was to determine the generality of the original observation (now by training animals on an alternative avoidance schedule) and, second, to determine the conditions required for the disruption of avoidance performance in the heat.

SUBJECTS

The same six male Sprague-Dawley rats participated in both experiments. They were housed in individual cages in a constant temperature room ($25^{\circ} \pm 1^{\circ}\text{C}$) and were fed and watered ad lib at their home cage.

APPARATUS

Standard operant conditioning chambers, programming equipment for a Sidman avoidance program, and data collecting apparatus were used (cf. Barofsky, 1969). The 2-mA shocks, lasting 0.5 sec, were delivered by a Grason Stadler shock generator and scrambler, Model E1064. Heat exposure (35°C or greater) occurred in

an environmentally controlled room. In Experiment 2, two rats were implanted with a temperature-sensitive transmitter (Model 196 TA, American Electronics Laboratory).

PROCEDURE

Experiment 1

Pairs of rats were given their initial training at one of three S-S intervals (5, 15, or 30 sec) with the R-S interval fixed at 20 sec. The rats received 48 h of training (8- or 16-h continuous sessions) under these schedule parameters. This was followed by 12 2-h sessions at each S-S interval, with order of exposure to the S-S interval being counterbalanced between animals. The 11th session was always at 35°C . The 12th session at 25°C

provided an estimate of the recoverability of performance following a heat exposure.

Rectal (T_{re}) and skin (T_s) temperatures were simultaneously taken for at least 5 min, but not more than 10 min, before a session and within 1 min of completion of a session. Temperatures were sensed by a small-mammal rectal thermister (YSI Model 402) inserted 8 cm beyond the anal sphincter and by a small surface thermister (YSI Model 421) attached to an elastic band that was applied to a shaved portion of the rat's back. Temperatures were indicated on a United Systems Corporation Digital thermometer (Model 502-3) in the 25° - 45°C range (calibrated to 0.01°C).

Experiment 2

Two weeks prior to the start of the experiment a calibrated temperature telemetering device was implanted, under aseptic conditions, into the intraperitoneal cavity of two rats. Each of these rats was paired with a previously trained, but now nonworking, control rat (i.e., a yoked control) and exposed to two extended avoidance sessions. The first session consisted of one continuous 7-h session at 25°C . The second session (1 week later) consisted of one continuous session, the first hour of

Fig. 1. The change in body temperature, from a measure taken 10 min prior to the start of the avoidance session, is plotted for both rats as function of time, ambient temperature, and session (circles, 25°C session; squares, experimental session). The length of each line underneath each temperature indicates the duration of exposure. The open arrows indicate examples of temperature regulation (i.e., stabilization of body temperature changes over time).

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which was at 25°C. This was followed by 90 min at 35°C, 1 h at 37°C, 1 h at 38°C, 1 h at 39°C, and, if performance persisted, 1 h at 40°C. The S-S interval remained fixed at 15 sec for both sessions.

RESULTS

Experiment 1

The response rate and heat content change were analyzed by a S-S interval, by ambient temperature, by Ss' analysis of variance, while the T_{re} analysis included a comparison between pre- and postsession T_{re} . The response rate did not vary significantly as a result of acute heat exposure ($F = 1.05$; $df = 2, 10$; $p > .05$), confirming the previous observation with discriminated avoidance (Barofsky & Hurwitz, 1968). The response rate, however, did vary as a function of the S-S interval ($F = 4.30$; $df = 2, 10$; $p < .05$) as originally found by Sidman (1966).

Rectal temperature did not vary significantly as a function of the S-S interval ($F < 1.0$) but did increase significantly as the ambient temperature increased ($F = 6.06$; $df = 2, 10$; $p < .025$). The postavoidance session T_{re} increased significantly above the presession T_{re} ($F = 179.07$; $df = 1, 5$; $p < .001$), although this increase varied as a function of the ambient temperature (i.e., an interaction effect; $F = 13.09$; $df = 2, 10$; $p < .005$). The mean presession T_{re} of 38.0°C increased to 39.4°C for both the session (25°C) before and after heat exposure and increased to 40.1°C for the 35°C session.

Avoidance performance resulted in heat storage, although the magnitude of the heat storage did not vary as a function of the S-S interval ($F < 1.0$), ambient temperature ($F = 1.88$; $df = 2, 10$; $p > .05$), or S. Heat storage

was calculated by determining the change in heat content of the rat from the beginning to the end of a session using the equation: heat content = the product of the specific heat of tissue (0.83), the body weight, and the mean weighted body temperature ($MWB = 2/3 T_{re} + T_s$) (Burton & Edholm, 1955; Caldwell, Hammell, & Dolan, 1966).

Experiment 2

Response and shock rate remained relatively stable for the 7-h session at 25°C. In the second session, the response and shock rate also remained relatively stable until the ambient temperature was elevated to 39°-40°C, whereupon a sharp and rapid drop in responding and increase in shock rate occurred for both animals.

The body temperature changes during both sessions are plotted in Fig. 1 for both rats. Note that the initiation of avoidance performance is associated with an increase in body temperature over time. At 25°C the maximum temperature was reached within 20 min of the start of the session, followed by a slow downward drift in body temperature which stabilized with time, reflecting a regulated state. This continued, as ambient temperature was increased, until a sudden and irreversible increase in body temperature occurred that was correlated with the disruption of avoidance performance.

DISCUSSION

The results of the first experiment demonstrated that acute heat exposure did not affect avoidance performance and that although body temperature increased in the heat, the animal remained in a thermally regulated state (i.e., no differential heat storage). The second experiment demonstrated that changes in avoidance performance occurred only when the animal was in an irreversible nonregulated state. This

contrasts with the previous observations for appetitively reinforced performance, where changes in performance were the means whereby temperature regulation was achieved in the heat (Barofsky, Robinson, & Hurwitz, 1970). These results, therefore, are consistent with the hypothesis that continued avoidance performance in the heat contributes to the regulation of body temperature. It also suggests that avoidance performance not only regulates an organism's exposure to noxious environmental stimuli, but also contributes to the regulation of a physiological process.

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